SUBJECT: Comparison of Sensitivity of Return Trajectories to Errors at TEI for Luna 16 and Apollo Case 310

DATE: November 25, 1970

FROM: R. J. Stern

MEMORANDUM FOR FILE

[redacted]

This memorandum contains data pertaining to the Luna 16 mission and a determination of the return trajectory for that mission. In addition, the sensitivity of errors at entry due to lunar launch or TEI injection errors are presented for the Luna 16 mission and a typical Hadley mission (7/26/71).

Pertinent data on the Luna 16 mission is presented in Table I. A patched conic program employing a direct impulsive lunar launch onto the earth return trajectory was devised. Trajectory parameters are presented in Table II for assumed reentry ranges of 120 and 300 NM. The short reentry range for the Luna 16 trajectory is based on the very steep ($\approx$60°) reentry angle employed for that mission. It can be seen that the lunar launch was near vertical requiring a ΔV of approximately 8660 ft/sec.* The fact that the trajectory from launch to the MSI is nearly rectilinear follows from the angular proximity of the lunar launch site and MSI exit point. The geographic return inclination of the trajectory for a 2 degree entry maneuver angle (120 NM) was 47.37 degrees. Since the earth landing latitude was approximately 47 degrees it can be seen that landing occurs near the high latitude point of the return geocentric ellipse.

Table III contains entry flight path angle errors, and down range and cross range miss errors at entry, resulting from launch velocity dispersions for Luna 16. Similar data for the Hadley TEI velocity are presented in Table IV. The sensitivities of the Luna 16 return trajectory are generally lower than those for the Hadley trajectory.

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2013-RJS-slr

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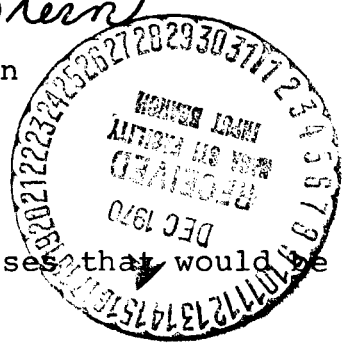
Attachments



*This does not include gravity losses that would be incurred with a finite burn.

Pages - 5
Code - none

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TABLE I

Luna 16 Data

Sept 12, 1970	Earth launch, 16:26 MT*
Sept 13	Midcourse correction
Sept 17	Luna 16 reaches the moon, enters a circular orbit with an altitude of 110 km period of 1 hour 59 minutes, and inclination of 70 degrees to the lunar equator.
Sept 18, 19	Performs corrective maneuvers resulting in an elliptical orbit with minimum altitude of 15 km, maximum altitude of 106 km, period of 1 hour 54 minutes and inclination of 71 degrees.
Sept 20	Lunar landing 8:18 MT, landing site 0° 14' latitude south, 56° 18' longitude east.
Sept 20, 21	Lunar stay approximately 24 hours
Sept 21	Lunar launch, 10:43 MT
Sept 24	Earth entry, reentry angle of 60 degrees
Sept 24	Earth landing, 8:26 MT, 50 miles southeast of Dzhezkazgan (47.48° N, 67.24° E), 250 miles from space facility at Tyuratem.

*Moscow time.

TABLE II

Return Flight Parameters for Luna 16

Flight Parameter	Reentry Maneuver Angle	
	2° (120 NM)	5° (300 NM)
Time of lunar launch	Sept 21, 10:43 MT*	Sept 21, 10:43 MT
Launch velocity	8664 ft/sec	8656 ft/sec
Launch azimuth	-117.9	-123.26
Launch flight path angle	89.50°	89.65°
Hyperbolic eccentricity	1.00005	1.0002
Time of arrival at moon's sphere of influence	Sept 21, 21:35 MT	Sept 21, 21:37
Earth-moon plane coordinates of MSI pierce point	2.4° N, 42.37°E	2.40° N, 42.55° E
Return inclination	47.37°	47.37°
Elliptic eccentricity	0.993850	0.993805
Perigee radius	869 NM	869 NM
Entry flight path angle	-60°	-60°
Entry speed	36107.6 ft/sec	36105.9 ft/sec
True anomaly at entry	-120.62	-120.62
Landing coordinates	47.14° N, 67.73° E	46.68° N, 67.73° E
Transearth flight time	69.10 hrs	69.39 hrs
Time of earth landing	Sept 24, 7:52 MT	Sept 24, 8:10 MT

*Moscow time

TABLE III

Sensitivity of Luna 16 Trajectory

Dispersion	Dispersions at Entry		
	Flight Path Angle* (DEG)	Cross Range Miss (NM)	Down Range Miss (NM)
Launch Velocity Magnitude			
+5 ft/sec	-.70	46.4	-78.5
-5 ft/sec	+.68	-46.1	79.8
Launch Velocity Direction (in plane of motion)			
+5 ft/sec	-.16	17.4	-15.04
-5 ft/sec	+.13	-17.4	15.13
Launch Velocity Direction (out of plane)			
+5 ft/sec	-.28	-21.4	-28.6
-5 ft/sec	+.25	+21.4	+28.8

Dispersion = Dispersed FPA - Nominal FPA

Reentry Maneuver Angle = 5°

TABLE IV

Sensitivity of Hadley Return Trajectory

(Earth Launch 7/26/71)

Dispersion	Dispersions at Entry		
	Flight Path Angle* (DEG)	Cross Range Miss (NM)	Down Range Miss (NM)
TEI Velocity Magnitude			
+2 ft/sec	-1.79	-10.63	-221.3
+5 ft/sec	-3.87	-31.46	-477.2
-2 ft/sec	2.61	6.40	322.8
-5 ft/sec**	6.40	6.74	794.2
TEI Velocity Direction (in plane of motion)			
+2 ft/sec	-.085	-1.12	-10.41
+5 ft/sec	-.21	-2.84	-25.52
-2 ft/sec	.09	1.10	10.57
-5 ft/sec	.22	2.72	26.98
TEI Velocity Direction (out of plane)			
+2 ft/sec	.44	-.45	53.6
+5 ft/sec	1.15	-1.04	142.2
-2 ft/sec	-.40	.49	-50.3
-5 ft/sec	-.97	1.30	-120.6

*Dispersion = Dispersed FPA - Nominal FPA.

**Does not reenter (results given for APSIS).

Nominal Entry FPA = -6.4°
TEI Velocity = 8158.4 ft/sec
Transearth Flight Time = 78.8 HR

BELLCOMM, INC.

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